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Extinctions by catastrophe?

The suggestion that the disappearence of species from the surface of the Earth has been periodic has stimulated contradictory explanations and also a diversity of ways of dealing with information.

DOES the periodic extinction of species on the surface of the Earth arise because the Sun has a previously unknown dwarf companion which disturbs the Solar System's cometary cloud, or because the Solar System as a whole oscillates above and below the plane of the Galaxy? And, in any case, how solid is the assertion that during the past 250 million years, there has been a statistical regularity in the timing of the disappearance of large numbers of species from the surface of the Earth?

These questions are certain to be provoked by the group of five articles appearing on pages 709 to 720 of this issue. Professor Anthony Hallam on page 686 gives some of the reasons why open-mindedness on the last question is still appropriate. Readers who are perplexed by the stark contradiction between the two explanations now advanced should not, however, blame the authors of the two hypotheses but, rather, the conventions, acceptable and otherwise, which regulate, and sometimes fail to regulate, such developments.

One obvious difficulty is that all five of the articles now published refer in one way or another to an article by David M. Raup and J. John Sepkoski, of the University of Chicago, which appeared only in the February issue of the *Proceedings of the National Academy of Sciences* (**81**, 801-805; 1984). That publication is itself the culmination of a long process — a detailed compilation by Sepkoski (*Milwaukee Contr. Biol. Geol.* **51**, 125; 1982) of what is known about the dates of the extinction of species on the surface of the Earth, partial consideration by one or other of the authors of the significance of this mass of data and eventually their conviction that there is probably a periodicity of 26 million years in the occurrence of extinctions. This conclusion seems to have been formed in their minds by May last year, when one of the authors described the result at one of the Dahlem conferences in Berlin. The article in which the conclusion is embodied was submitted for publication the following October, and has now appeared in print.

There is nothing remarkable about this sequence of events. Raup and Sepkoski are not the first to have suggested that there may be a periodicity in the pattern of species extinction, and have been properly cautious in putting forward their new interpretation of the data. The problem is notoriously difficult. The fossil record is so poor that it is not possible to tell when individual species became extinct. It is necessary instead to work with taxonomic families, but even then it is possible to place their extinction only somewhere within the confines of a stratigraphical stage, of which 39, with different durations, are placed by international convention within the past 250 million years.

One obvious statistical pitfall is that the conventionally accepted pattern of stratigraphical stages might itself conceal a periodicity. Raup and Sepkoski break new ground in the analysis of data-sets thought to harbour periodicity by their use of computer-based tests of the reality of their inferred period of 26 million years. The authors themselves acknowledge that the conclusion that species extinction is a periodic phenomenon will be jeopardized if the stratigraphical time scale proves to be incorrect (Hallam, *op. cit.*).

So why have Raup and Sepkoski prevailed when others advocating periodic extinctions have done less well? Obviously it has helped that their statistical analysis has been done in a way that shows them to be fully aware of the pitfalls. But it is proper to acknowledge that the intellectual climate has changed in favour of catastrophism, especially now that Luiz and Walter Alvarez appear to have proved their original case that the massive extinction at the end of the Cretaceous period was caused by the impact of some extraterrestrial object (see *Science* **223**, 1174-1186; 1983). Indeed, Raup and Sepkoski themselves say at the end of their article that a biological explanation of their periodicity "seems incredible" and that they favour "extraterrestrial causes".

Extraterrestrial explanations they have now stimulated in abundance, partly because preprints of their article appear to have been freely circulated in advance of publication. What seems now to have happened is that the statement by two careful investigators that extraterrestrial phenomena may be responsible for mass species extinctions has been taken by the astrophysicists as a signal to put forward models to account for what may have occurred.

Two important issues arise from this, the first of them concerned with the process of professional communication and, in particular, with the great confusion that may be caused by the widespread circulation of preprints. This practice, usually intended as a courtesy to colleagues elsewhere (and welcomed by the recipients except when the effect is to pre-empt a patch of intellectual territory), can also be thoroughly unhelpful to other people. The most obvious complaint against the system is that it is discriminatory, excluding from the circle of those in the know people who happen not to be on the authors' mailing list. On this occasion, the first accounts of models to explain periodic extinction were so swiftly on their way to *Nature* that, if revision of their content had not been recommended, it would have been possible for them to have appeared in print before Raup and Sepkoski.

Confusion has been further augmented by the circumstance that a full account of the article by Davis *et al.* (see p.715) appeared in the *San Francisco Chronicle* in mid-February, and that a workshop on the subject (organized by Dr Luiz Alvarez) was held at Berkeley, California on 3 and 4 March, and has since been agnostically reported (*Science* **223**, 2178; 1984). (A representative of *Nature* was invited but could not attend, perhaps, in the circumstances, fortunately.) One result of these developments is that criticisms of some aspects of the group of papers now published are already flowing in.

Developments such as these constitute a kind of nonsense. In the normal course of events, it is entirely proper and indeed essential that people should talk about their discoveries at conferences, and give their colleagues advance notice of what they plan to publish, while the occasional publication of the details of some new discovery in the general press does not spell the end of the world. But the concatenation of all these events can create serious doubts in people's minds about the proper attribution of novel ideas to the participants.

The second issue raised by the two groups of articles now published is more interesting because it draws attention to the difference of what may be called style that appears to distinguish astrophysicists from, say, biologists. The models now proposed for periodic extinctions are lent credibility only because Raup and Sepkoski have put forward a conclusion that cries out for an explanation. Reflection will show that astrophysicists often have no other way in which to make progress. The fact that, on this occasion, two contrasting models seem to be equally plausible must, for the time being, be counted an unlucky accident.

John Maddox

Evolution

The causes of mass extinctions

from A. Hallam

THE traditional darwinian view has it that organisms evolve and become extinct primarily as a result of competitive interactions, with changes in the physical environment being of subordinate importance. It has, however, become increasingly apparent in the last few years that organic turnover through time is characterized by long periods of relative stability punctuated by geologically brief episodes of mass extinction, during which a significant proportion of the Earth's biota is killed off. Evolution is seen to have had a substantial opportunistic component, with survivors radiating into the ecological niches vacated by extinction. What caused the mass extinction events remains a contentious issue of enduring fascination, as witnessed by a clutch of papers in this issue of *Nature*, inspired by the recently published claim of Raup and Sepkoski (*Proc. natn. Acad. Sci. U.S.A.* 81, 801; 1984) to have detected a 26-million-year periodicity in the mass extinctions.

Palaeontologists have generally looked for an interpretation of mass extinctions in terms of changing geography or climate. Although as long ago as 1950 Schindewolf suggested that the spectacular end-Palaeozoic extinction event was caused by an increase in cosmic radiation and a number of other extraterrestrial hypotheses were put forward in the following years, in the absence of any supporting evidence none was taken very seriously. The situation changed radically in 1980 when Alvarez *et al.* (*Science* 208, 1095) reported an abnormal enrichment in iridium and other noble metals in clay layers at the Cretaceous–Tertiary boundary, and interpreted it as a by-product of an asteroid impact which caused an expulsion of terrestrial dust on such a scale that sunlight was blotted out for several weeks, causing the simultaneous extinction of plankton and dinosaurs and many other groups. The Alvarez paper generated great excitement and has already provoked a huge literature.

The matter has been taken a stage further by Raup and Sepkoski. Using Sepkoski's compilation of the temporal ranges of marine vertebrate, invertebrate and protozoan families and a combination of Fourier analysis and Monte Carlo simulation, they claim to have detected a statistically highly significant 26-Myr cyclicity in mass extinction events since the late Permian (~ 250 Myr). Though they do not commit themselves to any particular interpretation they favour an extraterrestrial cause because of the regularity of the cyclicity. By circulating a preprint of their paper they, in effect, invited astronomers to propose explanatory models. The astronomers have responded with alacrity and devote five papers in this issue to the subject.

Davis *et al.* (*Nature* 308, 715; 1984) and Whitmire and Jackson (*Nature* 308, 713 1984) have independently put forward a model that postulates the existence of an unseen companion star to the Sun, occupying a highly eccentric orbit. When near the perihelion it is brought into the dense inner region of a comet cloud and by perturbing the cometary orbits initiates an intense comet shower, leading to a series of terrestrial impacts lasting up to a million years. Schwartz and James (*Nature* 308, 712; 1984) and Rampino and Stothers (*Nature* 308, 709; 1984) instead propose galactic models. The former authors speculate that long-term changes in cosmic radiation flux due to the Sun's oscillation about the galactic plane have provoked sufficient alterations of the biosphere to cause mass extinctions. Rampino and Stothers' reanalysis of Raup and Sepkoski's data leads them to suggest an extinction cyclicity of ~ 30 Myr, which correlates strongly with a galactic cycle. Extinctions might have been caused when the Earth passed through interstellar gas or dust clouds, or intercepted a cometary shower. Alvarez and Muller (*Nature* 308, 718; 1984) have subjected the records of large impact craters to time-series analysis and conclude that most occur on a 28.4-Myr cycle. Because only 13 craters met their rigorous criteria, however, their conclusion must be viewed with caution.

In assessing the value of these speculative papers it is clearly necessary first to scrutinize the Raup and Sepkoski analysis on which they are based. The accuracy of the geological time scale used is obviously crucial if a convincing regular cyclicity is to be demonstrated. Of two recently published time scales, the Harland and the Odin, Raup and Sepkoski prefer the former without giving any reason beyond the fact that it is extremely similar to the Geological Society of America time scale. That is unsurprising since the compilers of both time scales uncritically used the same data (of Armstrong). As Raup and Sepkoski acknowledge, there are important differences between the Harland and Odin time scales, with only moderate correlation ($r = 0.48$), and there are further differences between these and a new Geological Society of London time scale to be published shortly. The problem is that before the mid-Cretaceous, the accuracy of Mesozoic dating is generally rather poor, with an error in the determination of stage boundaries of 5 Myr or more.

The 26-Myr cyclicity can only be valid if, despite the difficulties referred to above, the Harland time scale is the most accurate. Even then there would be problems. Thus Raup and Sepkoski predict on their cyclicity model a late Norian extinction event at 221 Myr, only 2 Myr earlier than the Harland date for the end of the Norian. But the Harland time scale assumes equal time spans of 6 Myr for the Norian and succeeding Triassic stage, the Rhaetian. This cannot be accurate, because the Norian has seven ammonite zones and the Rhaetian only one. Many authorities therefore believe the Rhaetian should be relegated to a substage of the Norian or abandoned altogether. Thus the late Norian extinction probably took place only 1–2 Myr before the end of the Triassic, dated as 213 Myr by Harland, 205 Myr by Odin and the Geological Society of London and 208 Myr by Armstrong (in the Odin volume), who has revised his older estimate as used by Harland.

Of twelve extinction events recognized by Raup and Sepkoski, the mid-Miocene and Olenekian ones are admitted to be dubious and should be eliminated from a rigorous analysis. The Bajocian, Callovian and Hauterivian events are minor and deviate by 6–8 Myr from the predicted cyclicity. Since the most precisely dated event, the end-Cretaceous, is used as the reference, this leaves only five events — the late Permian, Pliensbachian, Tithonian, Cenomanian and late Eocene — where the disparity with the Harland time scale is no more than 1 Myr. Bearing in mind the inaccuracy of stage-boundary dating (in the Odin time scale the end of the Tithonian is dated as 14 Myr younger than in the Harland time scale), the evidence hardly seems to warrant Raup and Sepkoski's bold conclusion that "It seems inescapable that the post-late Permian extinction record contains a 26-Myr periodicity".

Whereas the only evidence for an extraterrestrial cause of mass extinctions is the iridium anomaly at the Cretaceous–Tertiary boundary — and even that remains controversial — there is a wealth of evidence relating mass extinctions to events on Earth. As discussed at some length in my forthcoming article (*A. Rev. Earth planet. Sci.* 12, 205; 1984), the most obvious relationship is with sea-level changes, which have exhibited a cyclicity on more than one scale throughout the Phanerozoic. In several papers in the 1960s, Newell proposed that mass extinctions of marine groups took place as a result of the drastic reduction in area and quality of habitat when extensive epicontinental seas regressed because of a fall in the sea level. This seems to me to point the way to the best general explanation, but the truth is clearly more complicated. In some cases, as in the end-Pliensbachian and end-Cenomanian events recorded by Raup and Sepkoski, and also quite possibly in the end-Triassic, late Devonian and end-Ordovician events, it might have been anoxia (as recorded by the extensive black shales deposited during the immediately succeeding rise in sea level) that caused the critical deterioration of the environment; it

is noteworthy that the Cenomanian, Pliensbachian and Devonian events were not preceeded by significant falls in sea level. In other instances a change in climate is implicated. Thus, although the fall in sea level at the end of the Permian, Triassic, Cretaceous and Eocene would have extended the habitat area of large terrestrial vertebrates, they suffered mass extinctions perhaps because of an increased continentality of the terrestrial climate, with greater seasonal temperature extremes. There is good evidence that global air and seawater temperatures were falling well before the end of the Cretaceous and Eocene, and the fall in sea level at the end of the latter period may well have been linked with the initiation of the Antarctic ice cap.

Many problems and uncertainties remain, and there is much to be learned about the response of particular groups of organisms and whole ecosystems to changes in the physical environment; the plankton extinctions at the end of the Cretaceous are still an enigma. The point is that these problems are readily amenable to analysis, ideally by teams of palaeontologists working in conjunction with stratigraphers, sedimentologists and geochemists. Before astronomers indulge in further speculations about the cause of mass extinctions they would do well to learn something about the rich stratigraphical record of their own planet. □

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